# TWO-PHASE REDUCED GRAVITY EXPERIMENTS FOR A

## SPACE REACTOR DESIGN

Zenen I. Antoniak
Battelle - Pacific Northwest Laboratory
Richland, Washington

Future space missions researchers envision using large nuclear reactors with either a single or a two-phase alkali-metal working fluid. The design and analysis of such reactors require state-of-the-art computer codes that can properly treat alkali-metal flow and heat transfer in a reduced-gravity environment. New flow regime maps, models, and correlations are required if the codes are to be successfully applied to reduced-gravity flow and heat transfer. General plans are put forth for the reduced-gravity experiments which will have to be performed, at NASA facilities, with benign fluids. Data from the reduced-gravity experiments with innocuous fluids are to be combined with normal gravity data from two-phase alkali-metal experiments. Because these reduced-gravity experiments will be very basic, and will employ small test loops of simple geometry, a large measure of commonality exists between them and experiments planned by other organizations. It is recommended that a committee be formed, to coordinate all ongoing and planned reduced gravity flow experiments.

# INTRODUCTION

The Pacific Northwest Laboratory (PNL) of the Department of Energy (DOE) has been assigned the role of modeling the thermal-hydraulics of advanced multimegawatt (MMW) nuclear reactors. Various reactor concepts are being proposed by other DOE National Laboratories and by industry. This paper addresses the experimental requirements posed by one concept--where the reactor working fluid is a boiling alkali metal.

Future space missions envision the need for high power levels (up to hundreds of MWe), which are orders of magnitude greater than required by spacecraft launched previously. The concept that appears to have the best potential for supplying such power is a nuclear reactor-based one, with a heat engine and alternator providing the conversion of thermal to electrical power. Stringent weight, heat transfer, and compactness criteria lead to the use of an alkali metal heat transfer medium, with a boiling alkali metal (BAM) system offering significant advantages over a single-phase system with an intermediate heat exchanger. In any event, there is a crucial need for analytical tools that can simulate two-phase flows in a zero gravity (0-g) or variable gravity environment. Mature computer codes exist that consider single-phase liquid metal flow and two-phase steam-water flow, both in normal gravity. To be completely useful for the design and analysis of BAM reactors these codes will need to be modified to handle boiling alkali metals instead of water and to do it in variable gravity. Experimental 0-g two-phase flow data are needed to provide new models and correlations for flow regimes, drag, and heat transfer.

## Code Assessment and Changes Required for Modeling 0-g Convection

| Code Limits No. Phases | Validity of "Uncorrected" Run at 0 g | Estimated Trend of "Uncorrected" Values of | | Modifications Required | | | |
|---|---|---|---|---|---|---|---|
| | | Pressure Drop | Heat Transfer | Flow Regime | Friction Factor Correlation | Heat Transfer. Correlation | Turbulence Intensity |
| 1 | Good[a] | Same | Same | No | No[d] | No[d] | No[d] |
| 2, Homogeneous | Good[b] | Underpredicted | Overpredicted | No | Yes | Yes | No |
| 2, Multifield | Poor | Underpredicted | Overpredicted | Yes | Yes[c] | Yes[c] | Yes |

(a) For single-phase flow.
(b) Where homogeneous representation is applicable.
(c) Magnitude of changes depends on effect of flow regime correlations.
(d) No modifications needed at high flow rates. Possible changes at low flow where 1-g buoyancy effects could dominate.

TABLE 1

Data on alkali metal two-phase forced convection in a normal gravity field are extremely limited; reduced-gravity data are practically nonexistent (only mercury condensation has been studied somewhat). However, reduced-gravity experiments with two-phase flow of more common fluids (e.g., water, air/water, halocarbons) have been more numerous. A comprehensive literature survey of these experiments has been completed. Results of this survey indicate that both the nature of boiling alkali metal and reduced-gravity experiments and the acquired data have been limited in various ways. Thus the utility of these past experimental efforts to the design and analysis of a space reactor is marginal, and new experiments will have to be performed.

A number of other organizations are pursuing reduced-gravity experimentation, for MMW and other projects. Many of the planned experiments seek similar data, using similar fluids, test equipment, and NASA facilities. Cooperation among experimenters would benefit everyone.


## FACILITIES AVAILABLE FOR REDUCED-GRAVITY EXPERIMENTS

Ideally, a manned, orbiting space station would be available with extensive laboratory facilities for reduced-gravity research. Also, launch costs, as well as the costs of developing space-qualified test hardware, would be reasonable in terms of the resulting data. Neither criterion is met currently. Small, low-power experiments could be performed on the shuttle albeit with nonhazardous fluids. The competition for the scheduled shuttle flights was keen in the past, and tests had to be planned years in advance of actual flight. With the recent grounding of the shuttle fleet pending development of reliable booster seals, only conjectures can be made regarding the timing of a shuttle experiment. Sometime in the 1990s a permanent manned orbiting laboratory may become available. At this time it is not clear if any alkali-metal experiments would be permitted there; hazardous materials are taboo on the shuttle. Regarding launch and test development costs, no appreciable cost reduction is foreseen in the near future.

Given the situation described, shuttle experiments probably will not be performed within the time frame allotted for two-phase reduced-gravity experiments. For the majority of the experiments, earth-based facilities such as drop towers and aircraft will have to be employed. These present various limitations--the chief ones being the duration and steadiness of the reduced-gravity environment. Another set of constraints is imposed by scheduling and cost restrictions. The latter provide a strong incentive for cooperation among organizations involved in reduced-gravity experiments.


## PROPOSED TWO-PHASE REDUCED-GRAVITY EXPERIMENTS

The twin issues posed by experimental facility limitations and the difficulties inherent in working with alkali metals must be squarely faced by any realistic test program. Thus, the only viable approach is to perform, to the maximum possible extent, experiments with innocuous fluids such as air, water, and

Freon in place of the alkali metals. Only if the desired data were to be seriously flawed by replacement fluids will alkali metals themselves become the working fluids. At this time the feeling is that perhaps alkali metals might be acceptable for use in drop towers and the KC-135 aircraft, but they would present an unacceptable hazard in any other reduced-gravity test facilities.

The objective of the first experiment conceived here is a narrow one: to obtain data on two-phase flow regimes and pressure drop. This can be met through the use of an air-water mixture in a suitably instrumented test section. It is planned to perform most of the tests in the NASA/Lewis Research Center (LeRC) 5.2s drop tube, which is evacuated to $10^{-2}$ Torr prior to a test. However, because a large number of tests is foreseen, the small 2.2s drop tower will also be used in conjunction with the large drop tube. This tower is open to the atmosphere, and even when a drag shield is employed, the attainable g-level is approximately $10^{-3}$, versus $<10^{-5}$ for the tube. The high g-level, plus the short duration of freefall, may limit the utility of the 2.2s facility.

The experiment, depicted in Figure 1, will consist of a series of tests, done at various mass flow rates and qualities to accomplish a full mapping of zero-g adiabatic phenomena. It is anticipated that useful correlations of several important parameters will result; Table 2 lists those of interest. Data for the correlations will be provided by instruments and cine/video film records. The measurements will consist of pressures, mass flow rates, velocities, and void fractions; flow regimes will be obtained from the films.

The intent here is initially to map the flow fields against various parameters. Thus the quality and/or void fraction data will be graphed versus the total mass velocity, and versus $\Delta P$. The flow regimes associated with these parameters will be superimposed on the plots. Flow pattern maps will also be plotted. These maps will be compared, at 1-g and zero-g conditions. Trends ought to be evident, suggestive of which existing pressure drop correlation might be modified or corrected to extend its applicability to low-gravity situations. In the simplest case of homogeneous flow, a correlation might be of the form

$$- \left(\frac{dp}{dz}\right)_{\text{2-phase}} = - \left(\frac{dp}{dz}\right)_{\text{1-phase}} \phi^2 \quad (G, X, P, \text{ etc.})$$

where $\phi^2$ is known as the two-phase frictional multiplier.

## Desired Correlations

| Parameter | Function of |
|-----------|-------------|
| $\Delta P$ | G, X, flow regime, Fr, Bo |
| $\Phi$ | $\Delta P_{liquid}$, Re, G, $\alpha$, Bo |
| $\alpha$ | Fr, flow regime, X, Bo |
| Flow regime | G, X, Fr, $\alpha$, Bo |
| $K_I$ | G, $\alpha$, flow regime, Fr |

### Nomenclature

G = mass velocity, $kg/s\ m^2$

X = quality, $\dot{m}_{vapor}/\dot{m}_{total}$ (-)

$\Phi$ = two-phase pressure loss multiplier (-)

$\alpha$ = void fraction (local volume fraction), $V_v/V_{total}$ (-)

Fr = Froude number, $v^2/Dg$ (-)

Re = Reynolds number, $vD/\nu$ (-)

$K_I$ = interfacial friction coefficients(-)

Bo = Bond number, $\rho D^2 g/\sigma$

### TABLE 2

For advanced two-fluid two-phase flow models, the improved flow regime characterization along with pressure drops and (if possible) void measurements will help to develop improved models for interfacial drag. The nature of this adiabatic experiment, as well as of similar experiments exploring heat transfer and critical heat flux, is a fundamental study of heat transfer and fluid

flow phenomena. While these experiments have a definite goal, the data resulting from them ought to have broad applicability.

In fact, commonality with another experimenter has already been determined. A condensation experiment currently being performed by Texas A&M University on the KC-135 aircraft at Johnson Space Center (JSC) incorporates a boiler supplied by PNL. This boiler is instrumented to permit measurement of flow and heat transfer within it. This results in a net gain to both participants. Texas A&M University obtains the condensation data it seeks, while PNL simultaneously obtains some of the boiling data that it requires. The willingness of Texas A&M University to share its experiment with PNL has allowed us to acquire data well in advance of what the original plan, indicated on Figure 2, stipulated.
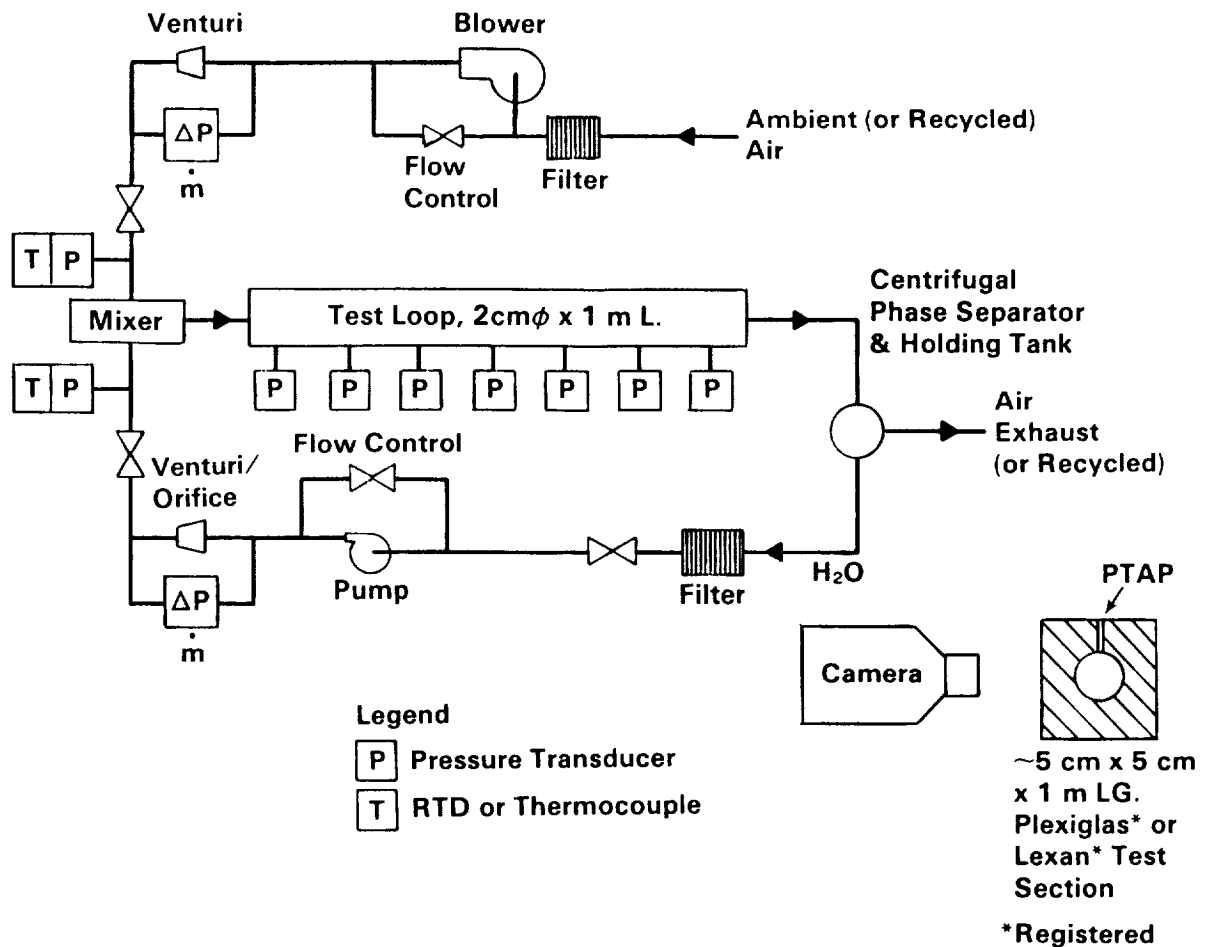
## Adiabatic Air-H₂O ΔP and Flow Regime Experiment



FIGURE 1

TWO-PHASE REDUCED-GRAVITY EXPERIMENTAL TASK FLOW

TIME
FRAME

TWO-PHASE REDUCED-g
EXPERIMENTS

ONGOING (NASA, UNIVERSITIES) —INFORMATION→ FUTURE EXPERIMENTS

1986    MONITOR — INFLUENCE — SPONSOR

PLANS

1987

$H_2O$, $NH_3$, FREON, AIR/$H_2O$      ALKALI METAL

1988    DROP TOWER    AIRCRAFT      1-g   >1-g   0-g MAGNETIC

1989    SHUTTLE      0-g

1990

ADDITIONAL ——→ |
FLIGHTS                 DROP TOWER    AIRCRAFT

1991                                SHUTTLE

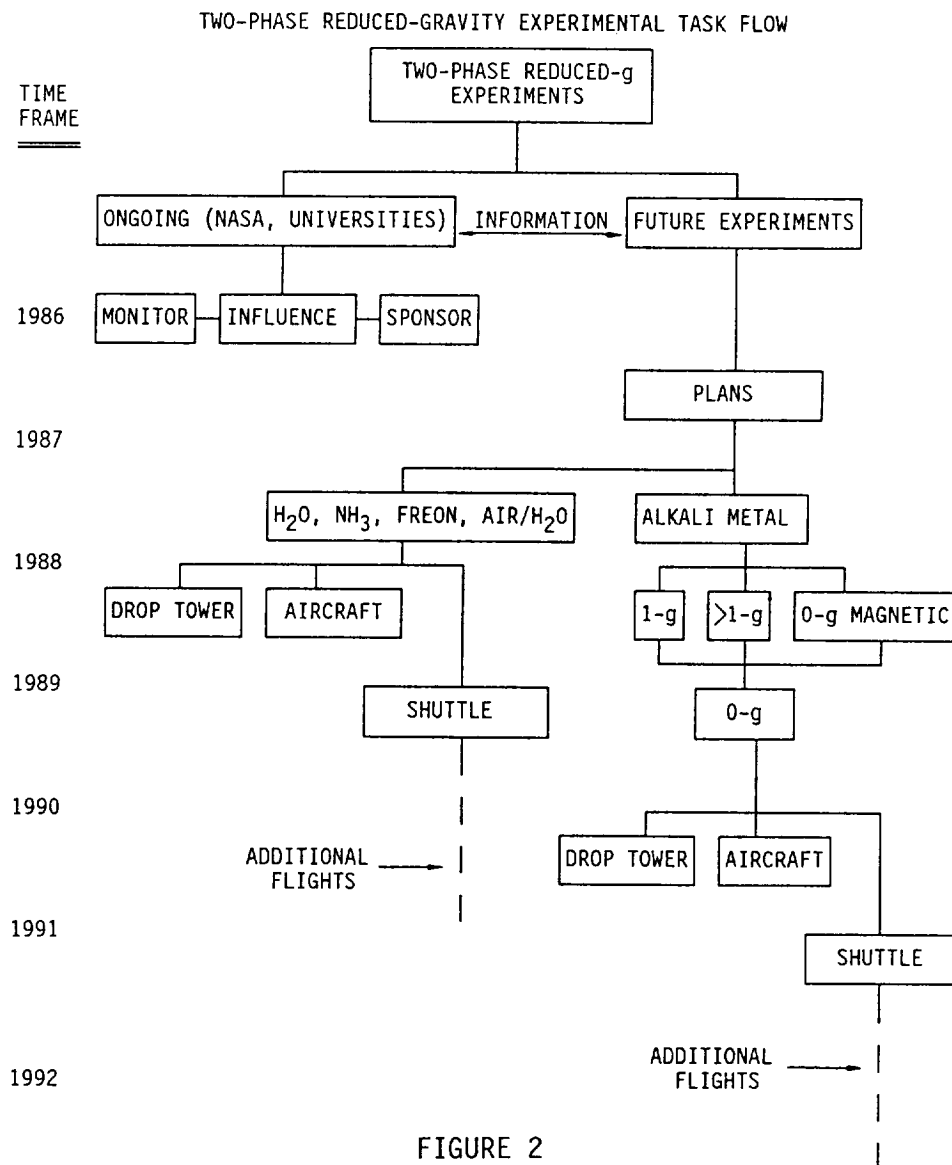ADDITIONAL ——→ |
1992              FLIGHTS

FIGURE 2

## SUMMARY

The MMW thermal-hydraulic reduced-gravity two-phase experiments, as described herein, will initially seek very basic information. These experiments will employ ordinary fluids and small test loops with simple geometries. The data obtained with these loops ought therefore to be of interest to other organizations and programs, which suggests that benefits would accrue to all participants in reduced-gravity research if experiments were coordinated. Currently, there exists no means for doing so. An example of the synergism possible is provided by the cooperative experiment by Texas A&M and PNL, as cited.

We highly recommend that a coordinating committee be formed, under Lewis Research Center's aegis. This committee would ensure sharing of information, tests, and data among all reduced-gravity researchers. We at PNL would like to participate in, and work with, such a committee.